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Effects of whole-body vibration training on physical function in patients with Multiple Sclerosis

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Abstract.
OBJECTIVE: The aim of this randomized controlled trial was to test the hypothesis that a three-week whole body vibration (WBV) training in addition to a standard rehabilitation program improves walking ability in patients with Multiple Sclerosis (MS).
PATIENTS AND METHOD: Sixty patients with definite MS were randomly allocated to the intervention or control group. Training sessions were performed three times per week for three weeks. Patients adopted a moderate squat position on a vibration platform. The training sessions comprised series of 3 × 60-sec exercise sets with increasing amplitude between sessions from 1 to 2 mm. During the exercise series, the vibration platform was turned on for the intervention group and switched off for the control group. A mixed factor ANOVA was used to compare sit to stand test, timed up and go test, 10-meter walk test, and 6-min walk test data between patient groups and between baseline and follow-up.
RESULTS: All outcome measures improved from baseline to follow-up ($P < 0.001$). The 6-minute walk test showed significantly greater improvements from baseline to follow-up for the intervention than for the control group ($P < 0.001$).
CONCLUSION: Determinants of walking ability in patients with MS that are specific to walking endurance tasks are most affected by vibration training designed to improve strength endurance.

Keywords: Walking ability, endurance, fatigue, rehabilitation, multiple sclerosis, whole body vibration, vibration platform, WBV

1. Introduction

Multiple Sclerosis (MS) is a progressive inflammatory and degenerative disease of the central nervous system [29], which predominantly affects young adults. Among the functional limitations associated with MS such as slower walking speed, reduced balance and diminished walking endurance [19, 33], fatigue is a very prominent symptom that is difficult to treat [15, 24, 25]. There is a great demand for improving training options and/or motivation to increase endurance in MS patients. In fact, in contrast to earlier beliefs, to date aerobic exercise and resistance training are well-tolerated and lead to beneficial effects in patients with MS [12, 14, 39].

In the last decade, whole body vibration training has received increasing popularity and scientific scrutiny. During whole body vibration training, athletes or patients perform their exercises while standing or moving on a vertically vibrating platform. Whole body vibration has been shown to augment endurance and fitness training in various sports [37, 46], the elderly [45] and neurological patients [13]. The vertical platform

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vibrations during whole body vibration training induce involuntary muscle contractions that are initiated by sensory receptors and reduce the recruitment threshold of motor units [7] presumably resulting in a more rapid activation of high-threshold fast-twitch muscle fibers [37].

Whole body vibration training has previously been suggested for application in MS rehabilitation [18, 42]. However, the results of whole body vibration training interventions in MS patients are inconclusive, and a recent Cochrane review suggested that there is insufficient evidence for the effect of whole body vibration training on functional performance in patients with MS [44]. For instance, in a four-week randomized cross-over pilot study on sixteen MS patients, additional whole body vibration training did not increase muscle strength and functional performance more than exercise alone although patients reported fewer muscle spasms [43]. Similarly, leg muscle performance and the functional capacity remained unchanged after 10- or 20-weeks whole body vibration training in MS patients [6]. In contrast, Alguacil et al. reported short-term improvements in time of response to recover from sudden disturbances during stance suggesting that whole body vibration training is a possible therapeutic tool for maintaining balance and posture [1]. Similarly, a three-week exercise program on a vibration plate significantly improved muscle strength, but not functionality, in persons with MS [9], and balance and walking time improved after a 3-week whole body vibration training without any adverse effects [30]. Clearly, there is insufficient evidence regarding the benefits of whole body vibration training on signs and symptoms of MS [40].

Most previous studies on whole body vibration training have focused on outcome parameters describing muscle strength, physical function and balance [1, 6, 9, 30, 43]. However, one of the main functional limitations associated with fatigue in MS patients is their reduced walking ability. The ability to walk longer distances is especially important for performing tasks of daily life such as going to grocery shopping or meeting friends. Hence, improving a patient's walking ability is a major objective of interventions in MS patients. Nonetheless, to date limited information on the effect of whole body vibration training on walking ability in MS patients is available.

The purpose of this study was to test the hypothesis that a three-week whole body vibration training in addition to a standard rehabilitation program improves walking ability described by muscle strength and balance performance (sit to stand test) and by the coordination (timed up and go test), speed (10-meter walk test) and task-specific endurance (6-min walk test) aspects of mobility in MS patients more than a standard rehabilitation program alone.

2. Methods

2.1. Study design

This three-week randomized controlled trial was approved by the local ethics committee and was conducted in accordance with the Declaration of Helsinki. Patients were randomly assigned to one of two groups, by a list of numbers between 0 and 1. All numbers occurred with the same frequency. Patients who were allocated a number below 0.5 were assigned to the intervention group (whole body vibration training), and patients who were allocated to a number above 0.5 were assigned to the control group. Group assignments were made by a trainer, and one of the investigators (C.H.) applied all tests. Baseline tests and follow-up tests were conducted at the same time of the day following a strict protocol. The investigator performing the test (C.H.) and the neurologist (C.D.) determining the EDSS score were blinded to the group assignment. Patient's group memberships were not disclosed to the investigators until study completion.

2.2. Patients

Participants for this clinical trial were recruited from MS patients residing in the rehabilitation clinic. Patients participated in an individually tailored interdisciplinary rehabilitation program covering different aspects of physiotherapy, occupational therapy, neuropsychology and speech therapy. Therapies were delivered in individual one-on-one sessions or group sessions. Inclusion criteria were: definite MS according to modified McDonald criteria [36]; limited walking capacity; Expanded Disability Status Scale (EDSS; ranging from 0 – no symptoms to 10 – deceased [26]) between 2 and 7; and motivation to participate in endurance training. Exclusion criteria were: Mini-Mental-State Examination <24 [23]; contraindications for whole body vibration training including acute fractures, a pacemaker, endoprosthesis in hips or knees and type 2 diabetes mellitus.

Eighty-four ambulatory MS patients volunteered to participate in this study after giving written consent

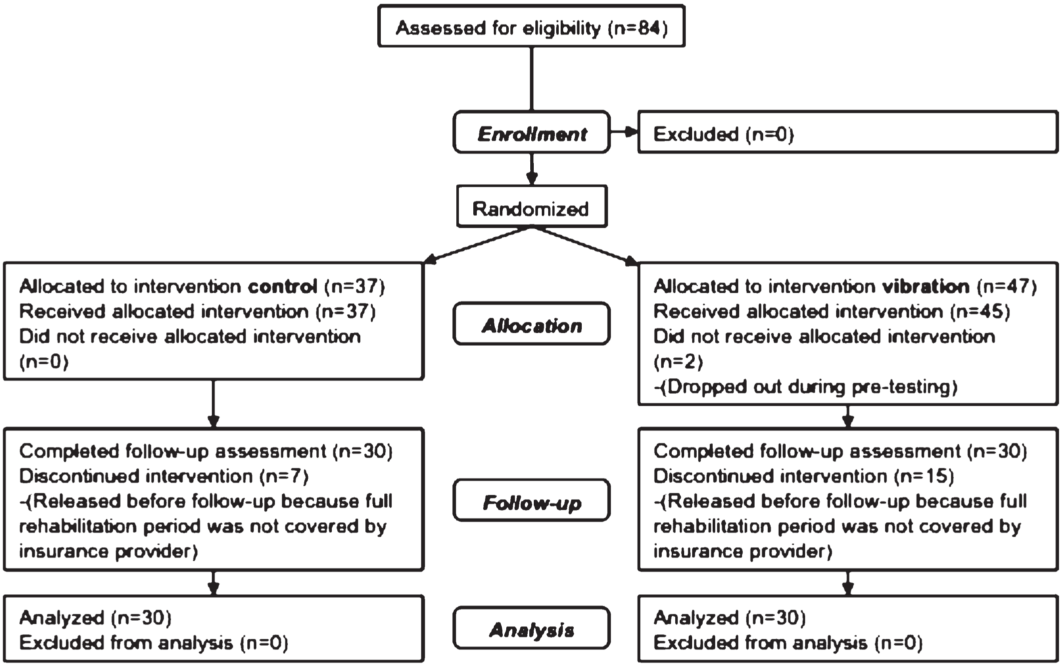

Fig. 1. Consort flow diagram of enrollment procedure.

(Fig. 1). Forty-seven patients were assigned to the intervention group and underwent the whole body vibration training. Thirty-seven patients were assigned to the control group and were instructed to complete the same exercise as the patients in the intervention group without turning the vibration plate on. Twenty-two patients were discharged before the end of the intervention period (intervention group, $n = 15$; control group, $n = 7$) because their insurance provider unexpectedly did not cover the entire rehabilitation period. Two patients in the intervention group were not able to hold the required position. Sixty patients were included in the final analysis (mean ± 1 standard deviation, age 43.3 ± 8.3 years, 45 females).

Thirty patients in the intervention group and 30 patients in the control group completed the protocol. Sex distribution, age, EDSS and FSMC scores (motor and cognitive) did not differ significantly between patients included or excluded from the study ($P > 0.230$; assessed using chi-square tests and independent t-tests).

2.3. Intervention

Patients completed three training sessions per week for a three-week period. The protocol was limited to three weeks because most patients typically stay at the rehabilitation clinic for four weeks. Whole body vibration training was supplemental to the standard rehabilitation program and performed between 4 pm and 7 pm outside of the rehabilitation clinic's regular training sessions. Patients were individually supervised and used the Borg-Scale (range, 6 to 20; 6 – no exertion at all; 20 – maximal exertion) [5] to estimate the intensity of each exercise set.

The intensity of the whole body vibration training and the training schedule were determined in a pilot study evaluating a tolerable training volume and intensity with the goal to increase strength endurance. First, patients in the intervention group completed a warm-up exercise consisting of three series of 30-second moderate squats with the upper limb at a 60° angle from the vertical axis performed on the vibration platform with 30-second rest periods between squats. Subsequently, patients in the intervention group performed three series of 60-second moderate squats while standing on the vibration platform (Power Plate pro5, Power Plate International, London, U.K.) vibrating at 30 Hz. The training was executed in a static squat position on the moving platform loaded only with the patients own body weight. The training intensity was increased throughout the three-week training period by reducing the rest period between the 60-second sets (first three training sessions: 30-sec rest periods between squats; subsequent training sessions: 5-sec rest periods between squats) and increasing the vibration amplitude (first six training sessions: 1 mm; last three training sessions: 2 mm). During the rest periods, patients were asked to stand in an upright position. Each whole body vibration training session lasted for a maximum of 12 minutes including preparation and Borg-scale testing.

Patients in the control group were instructed to complete the same exercise as the patients in the intervention group without turning the vibration plate turned on.

2.4. Outcome measures

Measurements of walking ability included strength, coordination, mobility, gait velocity and task-specific endurance parameters. Strength was measured by the sit to stand test [4, 10]. The coordination component of mobility was determined by the modified timed up and go test [35]. The speed component of mobility was evaluated by the 10-meter walk test [38], and the task-specific endurance component of mobility was assessed by the 6-min walk test [27]. All tests were carried out before and after the 3-week study period. The instruction for all tests was standardized and provided by the same person.

2.4.1. Sit to stand test

The patients were asked to rise from sitting on a chair five times consecutively as quickly as possible with their arms akin [32]. Time was taken from rising from the chair during the first repetition and stopped when touching the chair after the fifth repetition. The height of the chair was adjusted to ensure a knee angle of 90° in the start position. The patients were instructed to rise completely to an upright position before sitting down again.

2.4.2. Timed up and go test

The patients were asked to rise from a chair and walk five meters at their individual walking speed. Patients were allowed to use their armrests while getting up but were not allowed to use any assistive devices. The time was taken from the moment the patients left the chair and was stopped when the patients reached the target line with both feet.

2.4.3. 10-meter walk test

The patients were asked to start from an upright standing position and walk 10 meters at their individual walking speed. The subjects were not allowed to use any assistive devices and thus were required to walk independently. Time was taken from the moment when their front leg passed the start line and was stopped when the second leg passed the target line.

2.4.4. 6-minute walk test

The patients were asked to walk for six minutes at their individual walking speed. The test was performed on a standardized track with a flat carpet surface at the clinic. The patients were allowed to rest but the time was not stopped during their rest period. The patients were required to walk independently without any assistance. The time was started when the first leg passed the start line, and the distance covered after six minutes of walking was measured. The walking track was 175 meters long, and hence those patients who reached the target line in less than six minutes had to turn around to continue their test. All patients were accompanied while walking but not allowed to talk during the 6-minute test.

2.5. Statistical analyses

SPSS Version 16.0 (SPSS Inc.; Chicago, IL, USA) was used for statistical analyses. First, data were checked for normal distribution using the Kolmogorow-Smirnoff-Test. Differences between the intervention and control groups were detected using Student's *t*-tests for independent samples for normally distributed parameters. Differences between the intervention and control groups were detected using Mann-Whitney-U-tests for non-normally distribution parameters. Analyses of variance (ANOVAs) were used to detect significant time effects and time-group interactions with time and group membership as factors for all four tests describing walking ability. To test for a possible influence of fatigue on the intervention effect, motor FSMC score was included as covariate in the model.

3. Results

None of the patients experienced any serious side effects during the vibration intervention. Overall average EDSS scores were 3.3 ± 1.5 (corresponding to a level between light and moderate impairment; Table 1). The mean scores on the Fatigue Scale for Motor and Cognitive Functions [34] indicated severe motor fatigue (>32) and moderate cognitive fatigue (28 to 34) in both patients groups (Table 1). Baseline clinical characteristics (Table 1) and parameters describing walking ability (Table 2) did not differ significantly between the intervention group and the control group ($P > 0.300$).

Table 1
Mean ± standard deviation baseline characteristics of the intervention (whole body vibration training) and the control groups

Study groups	Intervention group	Control group
N	30	30
Gender [female/male]	22/8	23/7
MS Type: RR/PP/SP	24/2/4	21/4/5
EDSS	3.5 ± 1.2	3.3 ± 1.3
Age [years]	43.5 ± 10.0	43.9 ± 7.5
FSMC motor	36.5 ± 9.2	37.6 ± 6.9
None	1	3
Mild	1	3
Moderate	3	3
Severe	25	21
FSMC cognitive	32.5 ± 10.8	29.5 ± 10.9
None	9	5
Mild	3	6
Moderate	4	5
Severe	14	14

RR—relapsing-remitting; PP—primary-progressive; SP—secondary-progressive; EDSS—Expanded Disability Status Scale [26]; FSMC—Fatigue Scale for Motor and Cognition [34].

Patients in both groups showed significant improvements in their walking ability. Performance in the sit to stand test increased by 16.7% and 16.3% from baseline to follow-up in the intervention and control groups, respectively ($P < 0.001$ for both; Table 2). Similarly, performance in the timed up and go test increased by 6.1% and 11.3% from baseline to follow-up for the intervention and control groups, respectively ($P < 0.001$ for both). 10-m walk performance at follow-up was 10.5% and 9.5% better than at baseline in the intervention and control groups, respectively ($P < 0.001$ for both). Finally, patients in the intervention and control groups walked 14.7% and 3.3%, respectively, further in the 6-minute walk test at follow-up compared to baseline ($P < 0.001$ for both).

The 6-min walk distance was the only parameter describing walking ability that showed a significant time by group interaction ($P < 0.001$). Patients in the intervention group had a 4.5-fold greater increase ($P < 0.001$) in walking distance in the 6-min walk test due to the intervention compared to that in patients in the control group (Table 2). Individual changes in performance in the 6-min walk test from baseline to follow-up for both groups are illustrated in Fig. 2.

4. Discussion

The purpose of this study was to test the hypothesis that a 3-week whole body vibration training in addition to a standard rehabilitation program improves walking ability in MS patients more than a standard rehabilitation program alone. While patients in both groups showed better performance in all tests at follow-up than at baseline, the performance improvement was significantly greater in the intervention group than in the control group only for the 6-min walk test. Hence, the results of this study partially confirm the study hypothesis.

The result that not all aspects of walking ability are affected by vibration training in patients with MS is in agreement with results reported in the literature [6, 9]. The four tests used in this study describe four different aspects of walking ability. The sit to stand test represents a measure of muscle strength and balance performance [32], the timed up and go a measure of the coordination component of mobility [35], the 10-meter walk test a measure of the speed component of mobility [2], and the 6-min walk test a measure of the task-specific endurance component of mobility [22]. Hence, the results of this study suggest that a 3-week whole body vibration training specifically aimed at improving strength endurance only affects walking endurance but not muscle strength, coordination and walking speed.

In healthy adults, the 6-min walk test is a measure for respiratory fitness in healthy adults [17], and

Table 2
Mean ± standard deviation walking ability and endurance at baseline and at follow-up for the intervention ($N = 30$) and control ($N = 30$) groups

Parameter	Group	Baseline	Follow-up	*P*-Value	
				Time effect	Group × time interaction
Sit to stand [sec]	Intervention	12.6 ± 4.5	10.5 ± 3.9	**<0.001**	0.963
	Control	12.9 ± 5.5	10.8 ± 3.9	**<0.001**	
Timed up and go [sec]	Intervention	6.6 ± 2.3	6.2 ± 2.6	**<0.001**	0.246
	Control	7.1 ± 2.5	6.3 ± 1.5	**<0.001**	
10 m walk [sec]	Intervention	9.5 ± 4.3	8.5 ± 3.6	**<0.001**	0.636
	Control	9.5 ± 3.0	8.6 ± 2.6	**<0.001**	
6-minute walk [m]	Intervention	398.6 ± 114.2	457.0 ± 110.6	**<0.001**	**<0.001**
	Control	419.8 ± 100.5	433.8 ± 94.9	**<0.001**	

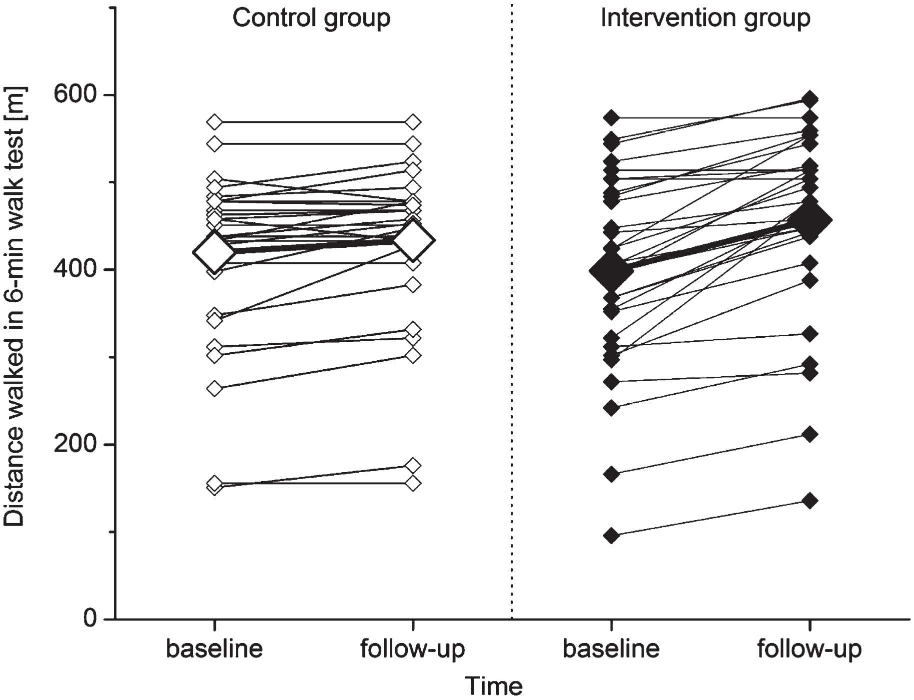

Fig. 2. Individual changes in performance in the 6-min walk test from baseline to follow-up for the control ($N = 30$) and the intervention ($N = 30$) groups. Patients in the intervention group had 4.5-fold greater increase ($P < 0.001$) in walking distance in the 6 min walk test due to the intervention compared to that in patients in the control group. The large symbols indicate the group means.

hence the results of this study suggest that the respiratory fitness of the patients in both groups in this study improved throughout the rehabilitation period reflected in longer 6-min walk distances at follow-up than at baseline. However, a recent study by Avelar et al. [3] concluded that—although vibration exposure may increase oxygen consumption and heart rate during squatting exercises—the minimum intensities required for achieving improvements in respiratory fitness are not achieved in this training regimen. Hence, the differences in 6-min walk test performance improvement in this study between the control and intervention groups are likely not caused by changes in their respiratory fitness but by improving patients' strength endurance.

Only few studies have applied the 6-min walk test in patients with multiple sclerosis. For instance, Chetta et al. [8] demonstrated that in patients with MS the results of the 6-min walk were significantly related to the severity of disability but not to subjective fatigue. In addition, a shorter distance covered during a 6-min walk test in patients with MS is associated limitations in activities of daily living, resting heart rate and subjective symptomatic fatigue in ambulatory patients with MS but not with respiratory muscle weakness, lung function and level of neurological impairment [41]. These results support the conclusion that the differences in 6-min walk test performance may be attributable to factors other than greater improvement in respiratory fitness in patients undergoing whole body vibration training.

Muscle strength and power are the main parameters that show improvements with whole body vibration training in healthy adults [7, 11, 37] and also in patients with MS [9, 18]. Although not measured in this study, an increase in muscle strength and endurance with whole body vibration training in patients with MS would presumably go along with improvements in all tests describing walking ability. The result that differences in baseline to follow-up improvements between the intervention and the control group were only observed for the 6-min walk test suggests that the neuromuscular control of the repetitive walking task improves with vibration training. However, it remains unclear if vibration training leads to neurological changes such as, for instance, a reduction in the use-dependent conduction block associated with fatigue in MS [31].

Walking ability data showed a large variability between patients in both groups both at baseline and at follow-up. MS is a complex disease that is characterized by a multitude of symptoms, and hence, patient groups are generally very heterogeneous in their symptoms and stages. The longitudinal design of this study primarily focused on within-patient differences between baseline and follow-up. However, it is feasible that there are several mechanisms of how whole body vibration training affects individual patients, which may explain the large variability in the data. In addition, patients underwent a standard rehabilitation program that is nevertheless tailored to each patient's individual need. Hence, differences in the content of the rehabilitation program between patients may have further contributed to the large inter-subject differences. We speculate that the effects of whole body vibration training on walking ability would be more easily detected in a more homogeneous MS patient group. However, until the exact mechanisms of how vibration training affects physiological and neurological parameters in these patients are identified, the effectiveness of such training in individual patients cannot be predicted.

Clearly, whole body vibration training affected specific aspects of walking ability in MS patients with severe motor fatigue and moderate cognitive fatigue. Hence, including vibration training in standard rehabilitation programs may benefit patients with MS because of resulting improved walking ability. Other benefits of whole body vibration training include increase in muscle performance [11], bone mass [16] and the prevention of articular cartilage loss during disuse [28] in healthy people. Hence, it is possible that whole body vibration training has other health benefits in MS patients whose mobility is compromised and hence their musculoskeletal structures are exposed to fewer, smaller and altered loads than those in healthy people predisposing MS patients to other comorbidities such as bone loss [20] or accelerated functional decline [21]. Further research into these associations is warranted before specific recommendations for the use of whole body vibration training in this population can be made.

The rehabilitation period in this study was limited to the four-week stay of patients at the neurorehabilitation clinic. In addition, the intensity and frequency of the whole body vibration training was moderate. It is possible that a longer period of vibration training at a higher intensity and frequency may result in more pronounced effects on walking ability that may differ from those of standard rehabilitation programs. Because parameters describing the neurological state of patients at baseline or follow-up were not assessed, statements regarding potential mechanisms of improvement in walking ability with whole body vibration training in these patients cannot be made. Nevertheless, the results of this study provide further evidence for the efficacy of whole body vibration training in patients with multiple sclerosis.

5. Conclusion

Determinants of walking ability in patients with MS that are specific to walking endurance tasks are improved by vibration training. The observed additive effect of whole body vibration training and a standard rehabilitation program on walking endurance provides evidence for the efficacy of whole body vibration training in patients with MS.

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Declaration of interest

The authors declare that they have no financial or other interest that would conflict the publication of this data.

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